A Question of Balance

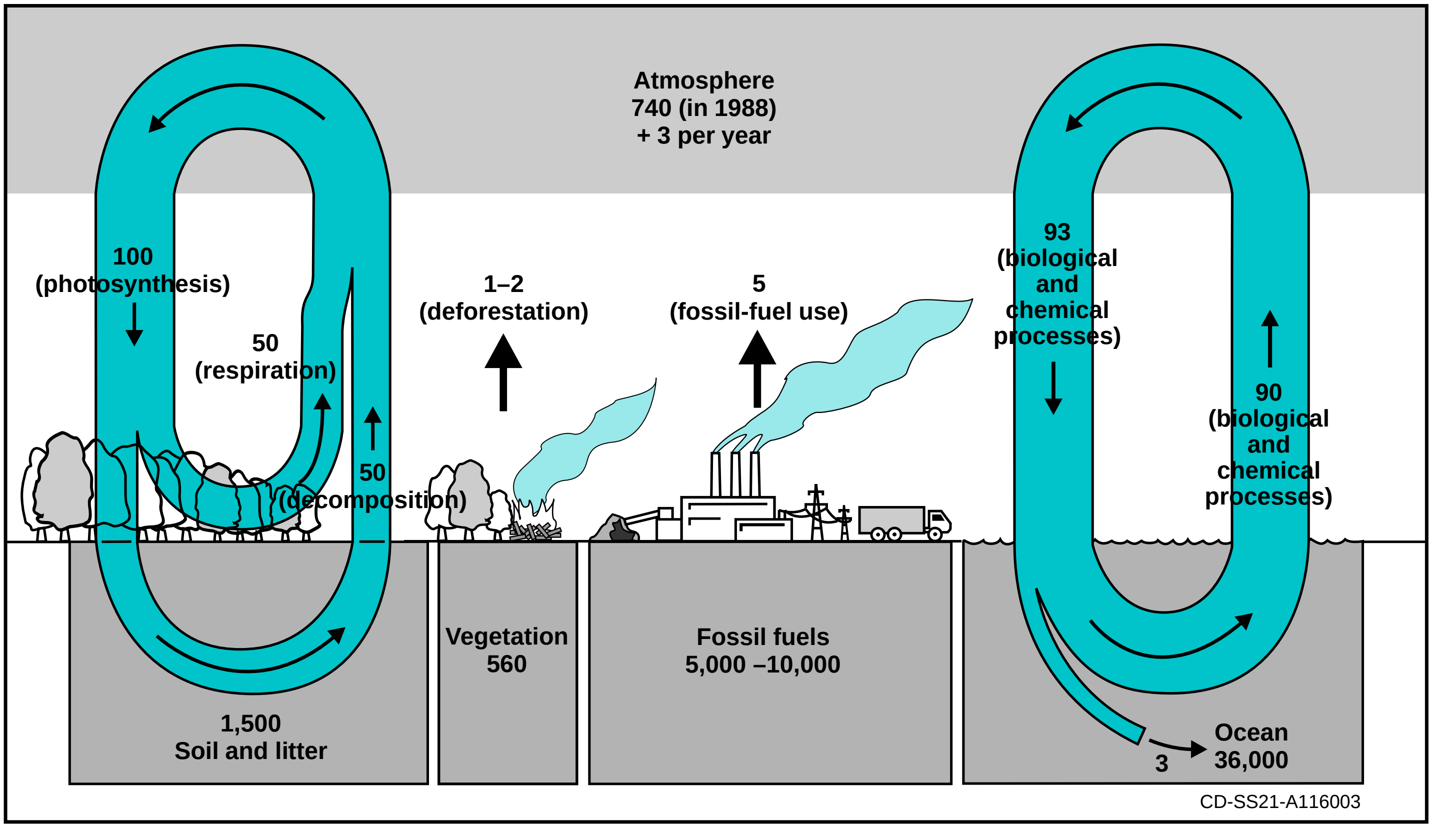
Ethanol from biomass could help forestall global warming while providing a renewable source of transportation fuel

by Gary Cook

Nature seeks a balance. We see it in the global carbon cycle, in which carbon is exchanged between the atmosphere, biosphere, and oceans through natural processes such as absorption, photosynthesis, and respiration. This constant exchange promotes an equilibrium in which atmospheric CO_2 is kept relatively steady over long periods of time. For the last 10,000 years, up to the 19th century, this global carbon cycle has maintained atmospheric concentrations of CO_2 between 260 and 290 parts per million (ppm).

We also see a balance between the solar energy the earth absorbs at the outer edge of the atmosphere (approximately 236 watts per square meter [W/m^2]) and the radiative energy that the earth transmits back to space. The radiative balance combines with atmospheric gases to promote the greenhouse effect, which warms the earth and supports life.

The surface temperature of the earth is about 15°C. At this temperature, the earth emits about 390 W/m^2 in long-length radiation to the atmosphere. Greenhouse gases like water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4) absorb much of this radiation to keep the radiative energy close to the earth. The difference between the energy emitted at the surface of the earth and at the outer edge of the atmosphere (currently about 154 W/m^2) is what warms the earth.



Carbon is exchanged between, and stored in, the atmosphere, biosphere, and the oceans. Deforestation and fossil fuel use are pushing the earth toward a new equilibrium.

Disturbing the balance

Human activity can disturb the equilibrium of the global carbon cycle. Since the beginning of the industrial age, man has interfered with the earth's ability to absorb CO_2 while releasing long-stored carbon to the atmosphere through the combustion of fossil fuels. As a result, atmospheric CO_2 has increased to 355 ppm and may double its pre-industrial levels by the middle of the next century.

This will increase the greenhouse-gas absorption of long-wavelength energy radiated from the earth. Offhand, this may seem to disturb the radiative balance, as less energy is radiated out of the atmosphere than is absorbed. Because of its tendency toward balance, however, nature will adjust by warming the atmosphere near the surface of the earth, which will increase the radiative energy emitted to space.

With a doubling of CO_2 in the atmosphere, the earth will be committed to a warming of up to 4.5°C. This could play havoc with the earth's climate—weather patterns, sea levels, crops—everything could be affected.

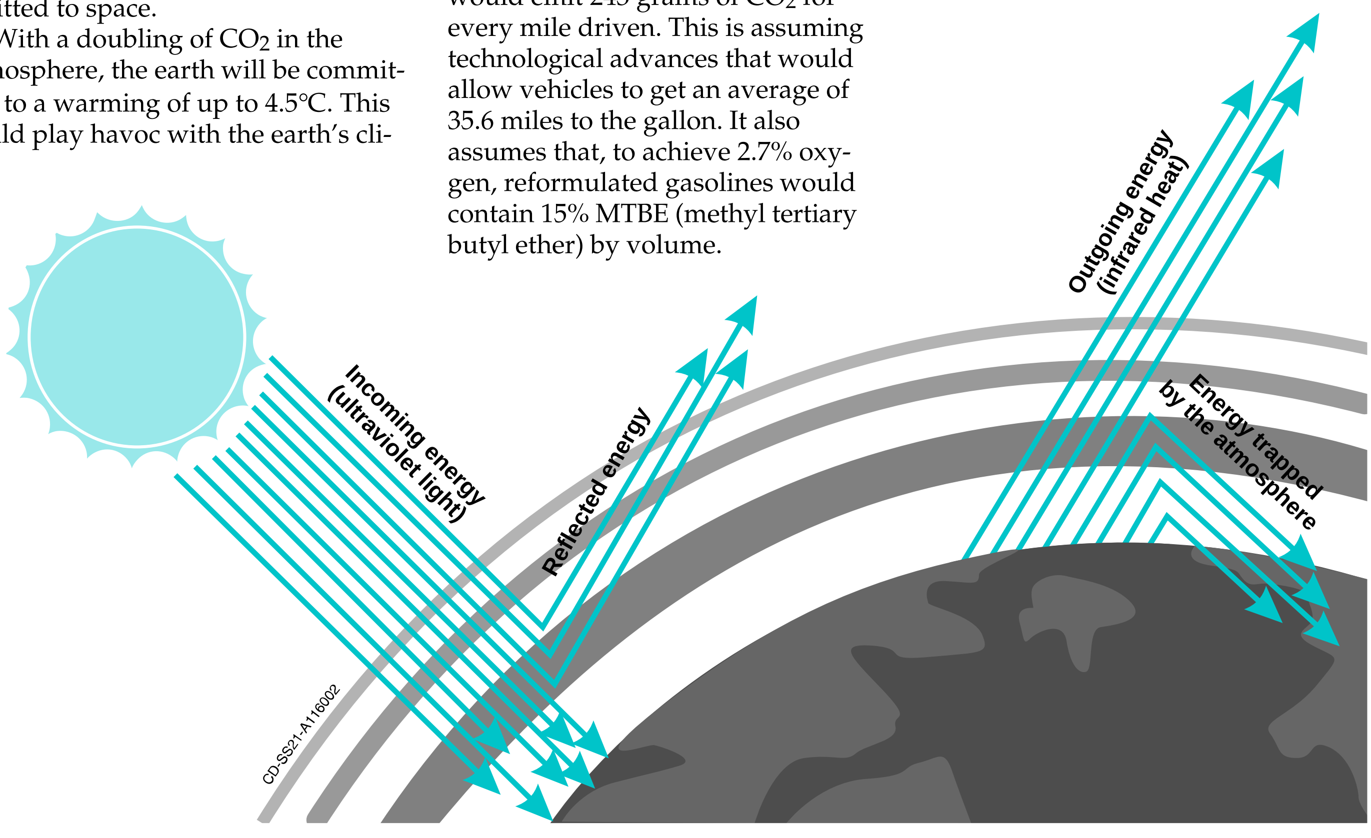
Ethanol fuels—addressing the CO_2 imbalance

We can mitigate the likely consequences of climate change by seeking a balance ourselves—a balance that will reduce the release of anthropogenic CO_2 to the atmosphere. A promising option is to displace gasoline with ethanol derived from lignocellulosic biomass (trees, grasses, and wastes).

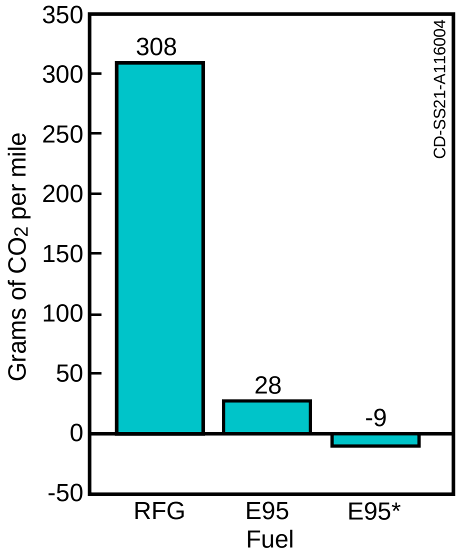
According to an analysis performed by NREL, Oak Ridge National Laboratory, and Pacific Northwest Laboratory (PNL), with support from other knowledgeable organizations, the average light vehicle running on reformulated gasolines (gasoline blends that reduce benzenes and aromatics and that contain at least 2.7% oxygen by weight) in 2010 would emit 243 grams of CO_2 for every mile driven. This is assuming technological advances that would allow vehicles to get an average of 35.6 miles to the gallon. It also assumes that, to achieve 2.7% oxygen, reformulated gasolines would contain 15% MTBE (methyl tertiary butyl ether) by volume.

This is just for combustion. If you count the CO_2 released during the entire gasoline fuel cycle—during production, refining, transportation, and storage—the average vehicle would emit an additional 47 grams of CO_2 for each mile traveled. If you then include the CO_2 released because of the electricity consumed during the fuel cycle, the average vehicle would emit another 18 grams of CO_2 per mile, for a total of 308 grams of CO_2 emitted for each vehicle mile.

Consequently, if U.S. vehicles travel the 2440 billion miles in 2010 projected by DOE's Energy Information Administration, the nation's cars and light trucks will emit nearly 755 million metric tons of CO_2. This does not take into account the CO_2 that would be emitted during the production, refining, storage, and



Carbon dioxide and other atmospheric gases create a greenhouse effect that helps warm the earth and support life. Incoming sunlight is partially reflected and partially absorbed. The earth radiates heat back toward space, and greenhouse gases trap some of the heat.



By 2010, E95 could emit less than one-tenth as much CO_2 as could reformulated gasoline (RFG). By factoring in electricity offsets and the carbon sequestered by soil, ethanol (E95) could even decrease the net CO_2 produced.*

transportation of MTBE added to reformulated gasoline.

Ethanol presents us with a far different story. According to the same study, the production, transportation, storage, and combustion of E95 (a mixture of 95% ethanol and 5% gasoline) would emit 28 grams of CO_2 per vehicle-mile—less than one-tenth the amount discharged by reformulated gasoline. This is assuming technological advances that, in 2010, would allow us to efficiently produce ethanol from lignocellulosic biomass and that would enable vehicles to achieve 28.25 miles per gallon of E95. But it does not take into account that soils used to grow biomass can store the equivalent of almost 16 grams of CO_2 per mile; if this is considered, then E95 would emit only 12 grams of CO_2 per mile—less than 4% of that released by reformulated gasoline.

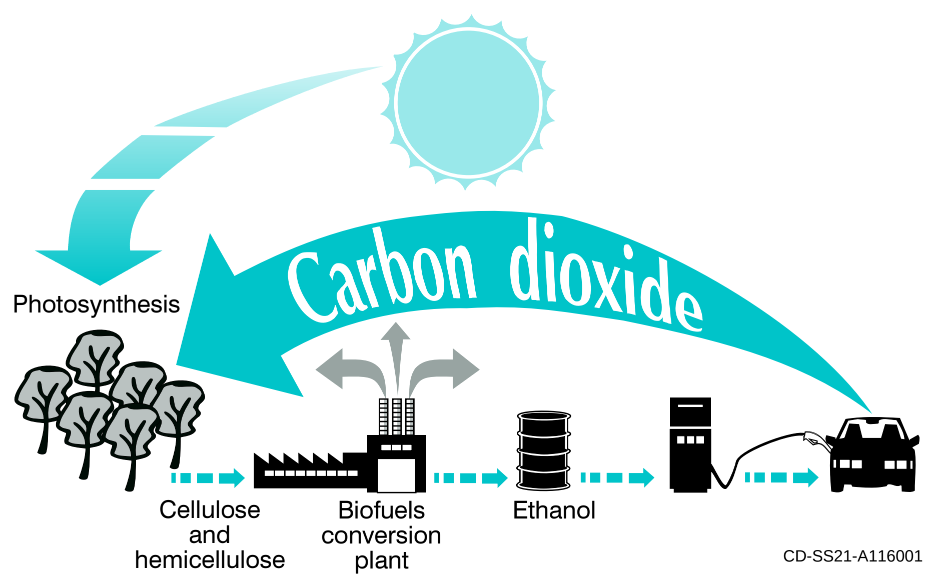
E95 produces so little net CO_2 because there is a natural balance—biomass grown to produce ethanol reabsorbs nearly all of the CO_2 generated by the production, conversion, storage, transportation, and combustion of E95. In fact, CO_2 emissions from E95 are positive only because vehicles that burn fossil fuel would be used to farm lignocellulosic crops and to transport ethanol fuel, and because 5% of E95 consists of reformulated gasoline.

Moreover, the lignin in biomass can be used to generate electricity. If the excess electricity produced with the lignin is sold to utilities, it will offset electricity produced by other means (primarily fossil fuels) and counter the CO_2 that may otherwise be generated. If we fold this offset into the calculations, we find that E95 could actually *decrease* the net CO_2 by 9 grams per mile.

An ethanol strategy

Although the study is a projection for 2010 based on assumptions of what would be technically feasible by that time, and it does not include emissions associated with all fuel-cycle inputs (mining, concrete, steel, etc.), the lesson is clear: by displacing gasoline with E95 derived from biomass, we would substantially decrease CO_2 emissions. In our scenario for 2010, for example, a 10% displacement of the gasoline used to power the nation's cars and light trucks would decrease total CO_2 emissions by as much as 75 million metric tons annually. (This reduction is equal to 20.5 million metric tons of carbon, approximately one-fifth of the total reduction called for in the President's Climate Change Action Plan.)

This is more than a strategy for displacing CO_2. It is also a strategy for wise energy use and for extending our fossil fuel resources. The production of ethanol from biomass has a favorable energy balance. We extract very little nonrenewable energy to derive a large amount of renewable energy. In 2010, the production of a gallon of ethanol would require about 178,000 Btu of energy inputs. But more than 164,000 Btu of this is energy from photosynthesis, and the rest is primarily fossil fuel—energy for feedstock production and harvesting. Because the energy from photosynthesis is renewable and "free," we sink only 13,800 Btu of nonrenewable energy into the process of producing 76,200 Btu of ethanol and 18,500 Btu of electricity—nearly



If we use ethanol fuels, the CO_2 released during harvesting, conversion, and combustion is roughly balanced by the CO_2 consumed in photosynthesis.

a 7-to-1 ratio of energy output to energy input.

Further in the future, we may be able to nearly eliminate the use of fossil fuels in this process by, for example, using renewable energy to farm lignocellulosic crops and to transport ethanol fuel. This would lead us toward a true, sustainable energy balance, without any contributions to climate change.

Because the transportation sector is responsible for about 32% of the CO_2 released in the United States, substituting ethanol for gasoline would pay huge dividends in the battle to stabilize CO_2 levels. The two other options for transportation—reducing vehicle miles traveled and improving vehicle efficiency—can also reduce CO_2 buildup, but not so dramatically as can ethanol from biomass.♦

The tops of four 9000-liter fermentation tanks protrude through the second-floor catwalk at the AFUF's process development unit.

A Facility for Future Fuels

Lignocellulosic ethanol could be an important weapon to combat global warming. Its widespread use could also help curtail urban air pollution problems due to excessive carbon monoxide, unburned or partially burned hydrocarbons, certain toxins, sulfur oxides, and other compounds.

Currently, this nation uses about 1.2 billion gallons of corn-derived ethanol annually, primarily in E10 blends (10% ethanol and 90% gasoline). This is roughly 1% of the total amount of transportation fuels used per year. If ethanol is to have an appreciable impact on air pollution, greenhouse gas emissions, and transportation, we must go beyond E10 to E85 (85% ethanol and 15% gasoline) and E95 fuels and beyond corn ethanol to ethanol derived from trees, grasses, and wastes. To do this, we must also move beyond the research phase in lignocellulosic ethanol.

NREL's new Alternative Fuels User Facility (AFUF) is crucial to this endeavor. The AFUF will provide the facilities needed to move advances in ethanol and other biomass research into the development phase. The facility includes a pilot plant and integrated start-to-finish process development capabilities. Two buildings at NREL are being joined to house the pilot plant. A new, 1580-m^2 building will house laboratories and offices.

The core of the AFUF is the process development unit located in a 743-m^2 area. Researchers from NREL and industry will use this pilot plant to explore fermentation technologies at a much larger scale than that possible in the laboratory. The process development unit's feedstock capacity of 900 kg per day will improve industry's assessments of the operability of the biomass-to-ethanol process and allow companies to test commercially available equipment. The larger scale will enable them to employ instrumentation to accurately confirm material and energy balances and to check the effects of heat and mass transfer.

When the process development unit starts up later this year, it will employ four 9000-liter fermentation tanks. Depending on funding, five more fermenters may be added in 1995 to allow researchers to ferment cellulose and hemicellulose sugars simultaneously and produce cellulase enzyme.

The AFUF will also contain two bioprocessing integration laboratories where industry researchers can test operations and processes that are linked as they would be in actual production. Process integration will identify key chemical and biological interactions between various steps. Industrial partners will work with NREL to utilize the results from process integration to identify the best processes for pilot-plant trials in the process development unit.

Other AFUF facilities will include research laboratories for bench-scale fermentation and enzyme production; a feedstock pretreatment laboratory; analytical laboratories; and office, conference, and observation areas.—*Gary Cook*